

Figure 1: Power from a variable speed supply fan is displayed on a carpet plot. The plot correlates the electricity use of a building supply fan in kilowatts against the time and day of use on the x and y axes, respectively.

Building Data Visualization for Diagnostics

By Steven Meyers, Evan Mills,
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Accurate, appropriate information is essential to understanding the dynamics of energy use, control strategies, and occupant comfort in buildings. Performance data for a building are valuable at all stages of its life cycle—design, commissioning, and operation. However, transforming raw data into useful information and then into effective feedback to enable the key players (e.g. building operators, utilities, and energy service companies) to operate their buildings optimally is no small task. Even if a feedback system is in place, poorly organized and displayed data may not yield value to the building operator. This article presents the rationale for and methodological issues for the use of specialized data-visualization techniques, illustrated by five case studies for HVAC and lighting in commercial buildings.

Data visualization complements the process of data acquisition. For our purposes, it is defined as the display of a rich set of building variables and parameters in a way that permits the analysis of data at different timescales with the objectives of identifying or verifying the energy savings achieved by energy-efficient technology or identifying malfunctions in building equipment. Effective data visualization depends on designing graphic presentation formats that clearly reveal technical phenomena relevant to the performance of the building. Incorrect visualization can mask critical problems.

Today, engineering estimates of energy use and savings are the basis of most energy-efficient building design and retrofit projects. Unfortunately, in the field, these buildings

often perform significantly differently from design estimates, and their performance varies with time. Measured data can help verify energy savings, illuminate control and operational problems in a building, and test the accuracy of predictive methods. Such data are increasingly valuable in energy performance contracting, utility demand-side management program evaluation, and other activities where regulatory requirements or financial contracts require documenting actual energy performance and costs.

In recent years, data collection has tended towards increasing disaggregation into shorter timesteps and into specific end uses. With the availability of larger quantities of data comes the challenge of making sense out of the numbers. Rapid development of data-acquisition technology, computer workstations, and graphics software has made possible gathering and visualizing detailed buildings en-

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Editor's Note: A hypertext version of this article containing additional case studies is available on the World Wide Web at <http://eande.lbl.gov/CBS/DV>.

ergy data in new ways. Effective data visualization offers various energy and non-energy benefits:

- identifying anomalous or suspect values (e.g. from faulty sensors);
- identifying otherwise undetected malfunctioning systems that are jeopardizing energy savings, equipment life, safety or comfort;
- identifying poorly commissioned systems, i.e. where actual performance is inferior to that anticipated at the design stage;
- revealing desired or undesired correlation among multiple variables (e.g. mechanical systems, weather conditions, and operating factors); and
- identifying the minimum data timestep (minute-by-minute, hourly, daily, weekly, monthly) required to resolve critical phenomena.

Just as important as the information-enhancing benefits of using data visualization is rapid interpretation facilitated by visualization—this opens the door to real-time interactive feedback between the data analyst and building manager. As with other measures designed to achieve and maintain energy savings, the costs of data visualization must be weighed against the benefits. There is no general rule; different users of data have differing needs with respect to detail and accuracy. Regardless of the desired level of precision, effective data visualization adds value to the process of optimizing building performance.

Methods

• **Data collection:** This article addresses key issues of building monitoring pertaining to data visualization. The variables that need to be measured and the necessary accuracy and collection frequency of these measurements depend on the analysis to be performed on the data. Therefore, determining how they will be used is an essential first step before collecting data. The required individual sensor accuracy and data collection frequency can then be back-calculated to meet targeted objectives. Three options exist for collection:

1. In a *dedicated monitoring system*, sensors to measure temperatures, flows, pressures, electric power, and equipment status are connected to a central data logger. While having the obvious advantage of flexibility, dedicated monitoring systems are expensive (De Almeida et al. 1994; Heinemeier et al. 1992).

2. Collecting data through an *Energy Management Control Systems (EMCS)* that already exist in most large buildings has a significant cost advantage, but all of the desired sensors and accuracies may not be in place (Heinemeier and Akbari 1992; Heinemeier 1993).

3. A hybrid approach involves *combining EMCS data and hardware with dedicated monitoring equipment* to measure points not commonly monitored by an EMCS.

Recent advances in software for data visualization in the building sector have led to the development of a broad range of powerful visual diagnostic tools. Declining prices of powerful personal computers and workstations have made possible more data-intensive color displays that can add value to data. Various types of contour plots, psychometric charts, and 3-D surface plots help building operators diagnose complex problems in new ways. To add value, the graphics may be animated.

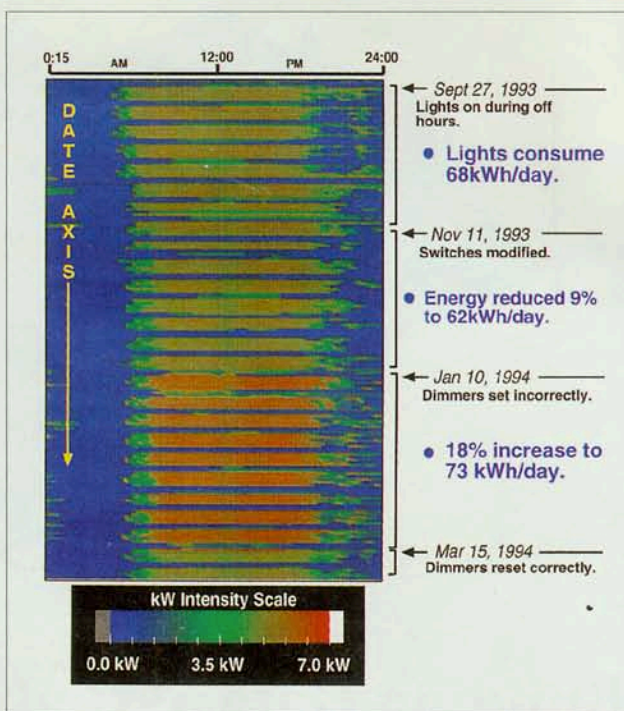


Figure 2: Contour plot shows the various operating stages of occupancy sensors on a bank of T-8 lamps in a California office building.

For large projects continuing over long periods of time, custom software and hardware may be developed to save future costs. For example, at a university campus, custom data acquisition software was written that interfaced with the existing hardware (sensors and A/D converters) of an EMCS to allow flexible and extensive data collection. This approach avoided the costs of instrumenting 40 campus buildings. The cost of monitoring is no longer proportional to the number points being monitored.

• **Types of Analysis:** Common displays such as time-series and scatter plots have been employed for decades (Liu, 1994). Recent advances in software for data visualization in the building sector have led to the development of a broad range of powerful visual diagnostic tools. Declining prices of powerful personal computers and workstations have made possible more data-intensive color displays that can add value to data. Various types of contour plots, psychometric charts, and 3-D surface plots help building operators diagnose complex problems in new ways. To add value, these graphics may be animated.

Advanced data displays convey both qualitative and quantitative information. A common application of qualitative data analysis is to verify that mechanical and electrical systems are running properly and only when required. Such information is essential to building operators because improper scheduling not only wastes energy, but may

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cause occupant discomfort and decrease equipment life. To effectively interpret quantitative results, detailed information such as nameplate data for the building's subsystems must be available. For example, if a sensor indicates that the air flow in a duct is 12,000 CFM (5663 L/s), but the mechanical plans indicate the fan is rated at 8,500 CFM (4011 L/s), something is malfunctioning or the wrong fan was installed. Also, original design parameters such as the expected coefficient of performance (COP) of a chiller at a given loading can be compared with the COP calculated from a plot of the monitored air/water flows and temperatures.

• **Tools for Analysis:** The type of visualization and the speed at which it is executed depend on the hardware and software available to the analyst. Currently available tools range from standard spreadsheet packages to high-end systems designed specifically for displaying monitored building performance data. Features useful for analyzing building data are described below. The day, date, and time should be easily correlated to each data value. Engineering units and specific pre-defined displays (such as load distribution and psychometric charts) should also be included. In buildings, meaningful trends occur on time scales ranging from minutes to years. A visualization system should be capable of handling both extremes. Large buildings can have hundreds of data points which are polled every one to sixty minutes for several years, a process that generates large data sets. It is also convenient to have access to all the monitored data at once because the "right" questions to ask about a system's performance are not always clear at first. Preliminary data analysis leads to questions requiring information from additional data points. For example, to address complaints of occupant discomfort in a particular zone, an operator may display a time-series of the zone and supply-air temperatures. This may confirm that a problem exists, but without simultaneous access to data from valves and motors in the zone's air-handler, it is unlikely that the operator will be able to diagnose and solve the problem.

Feedback

Maintaining a building involves a variety of players. Since advanced data visualization requires specific skills and hardware, the analyst may not be the person who makes the physical system adjustments or modifies the control system. A method of feeding the analysis back to the operations staff must be developed. It is important to develop an implementation plan emphasizing specific responsibilities to communicate results and develop a response. All players must understand why this analysis is being performed, and institutional barriers can challenge reaching this consensus (Lovins, 1989). For example, building operators may feel uncomfortable because another team is "intruding" on their area of responsibility. Building owners may not benefit from the expense of installing energy-efficient equipment and monitoring/visualization systems from which the tenants benefit through reduced utility bills. Also, in some cases, when the building's facilities department reduces the energy

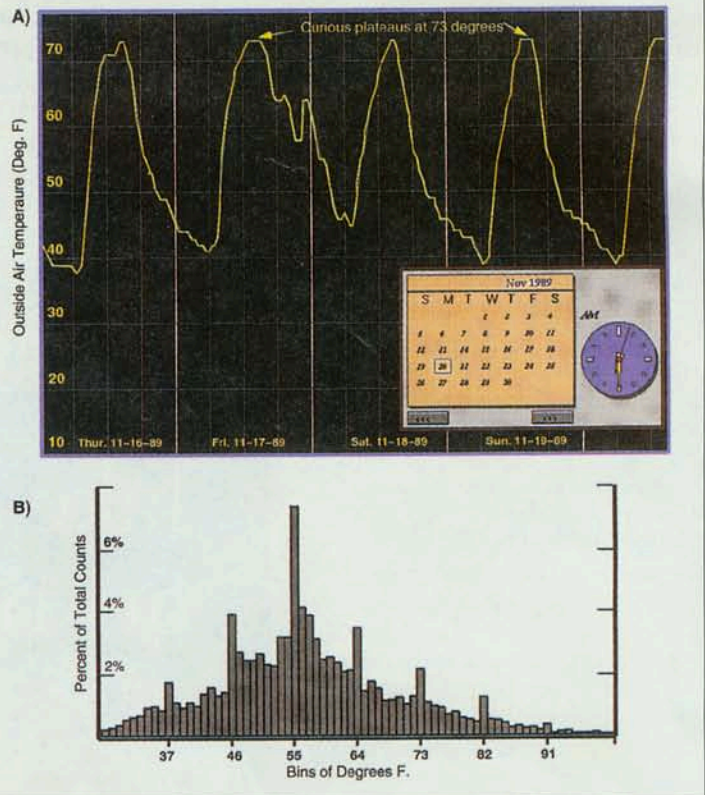


Figure 3: (A) shows time-series plot of the outside air temperature during a one-week period in Northern California. (B) shows histogram of the data which reveals an unsuspected problem with the sensor.

load, the building's owners respond by reducing their budget. To avoid these conflicting interests, a feedback system could include an incentive for building operators that produces benefits for all the parties involved in the building.

Case Studies

• **Malfunctioning Supply Fan Variable-Frequency Drive:** Motors that drive fans, pumps and compressors are often candidates for variable frequency drives (VFD) as energy conservation measures because their maximum flow is not always necessary to meet the building's load. However, these drives often perform sub-optimally (Kaplan 1994). Malfunctioning drives often go undetected because they usually fail in the full-speed mode and thus do not affect catastrophically the daily performance of the building. Simple displays of monitored data from VFDs allow building operators to determine quickly if a drive is performing to specifications.

When a supply fan and its variable frequency drive perform at less than the optimum level, the fan wastes energy and can damage the equipment. *Figure 1*, often called a surface or carpet plot, correlates the electricity use of a building supply fan in kilowatts against the day and time of use on the x- and y-axes, respectively. The interval in the plot represents a five-month period from April through September, 1993. Regularly spaced breaks in the data represent weekends. The fan ventilates a 22,000 ft² (2000 m²) office building in Northern California, an area with a hot, dry summertime climate. The plot shows a nighttime offset of 1.3 kW for a period of 4 months beginning in April 1993.

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The forest of spikes in the central part of the plot portray the fan's daytime usage pattern. These fluctuations show the fan power profile as the VSD varies the fan's speed.

At a glance, this plot tells the building manager that the EMCS is not shutting down the fan's VFD at night as it should prior to 6/1/93. The 1.3 kW of energy represents an unnecessary cost of perhaps a thousand dollars a year. From the perspective of a building manager, this is a small cost and is passed on to the building's tenants. What cannot be overlooked is the effect of this situation on a piece of capital equipment—the fan's motor. If a motor is not designed to run at low frequencies, it can overheat and burnout if driven too slowly by a VFD. The cost of a replacement motor is a "first cost" incurred by building maintenance, not by the office's tenants. Thus, in addition to a small energy saving for tenants, identifying this malfunction has produced a non-energy benefit to the building's owner.

Another interesting feature of this plot are the plateaus occurring on June 17 and 18. In this case, plateaus represent the intervention of a contractor who was performing some type of building maintenance such as duct balancing work, but they could just as well have indicated a critical system malfunction.

To ensure that the offset is a real problem, and not the result of a miscalibrated sensor, the building's energy manager can examine other types of data if available. The measurement of airflow over time would show higher than expected nighttime values. Another measurement is the static pressure in the building's supply air duct, for which well-established procedures are available in ASHRAE standards, and which would be elevated during nighttime hours of operation. Additional VFD case studies are available from the authors.

• **Recommissioning an Occupancy Sensor and Lighting Dimming Control:** During the commissioning of a new building or the retrofit of an existing one, contractors or operations personnel sometimes install measures that fail to save energy as planned because the measure was implemented incorrectly or because the unexpected behavior of occupants or interaction of the systems somehow defeats the measure.

The electricity usage of a bank of T-8 lamps between September 25, 1993 and March 29, 1994 is depicted in Figure 2 in a California office building. The lights, outfitted with occupancy sensors, illuminate 10,000 ft² (1000 m²) of the 22,000 ft² (2200 m²) building (Mills 1994a). The plot's dark-blue, regularly spaced horizontal lines represents weekends, when lights were mostly off. The dark vertical band on the left shows the off-hours of lighting energy use during the interval from midnight to about 6 a.m.

The plot reveals two problems with the lighting system's energy performance. The first is evident in the interval be-

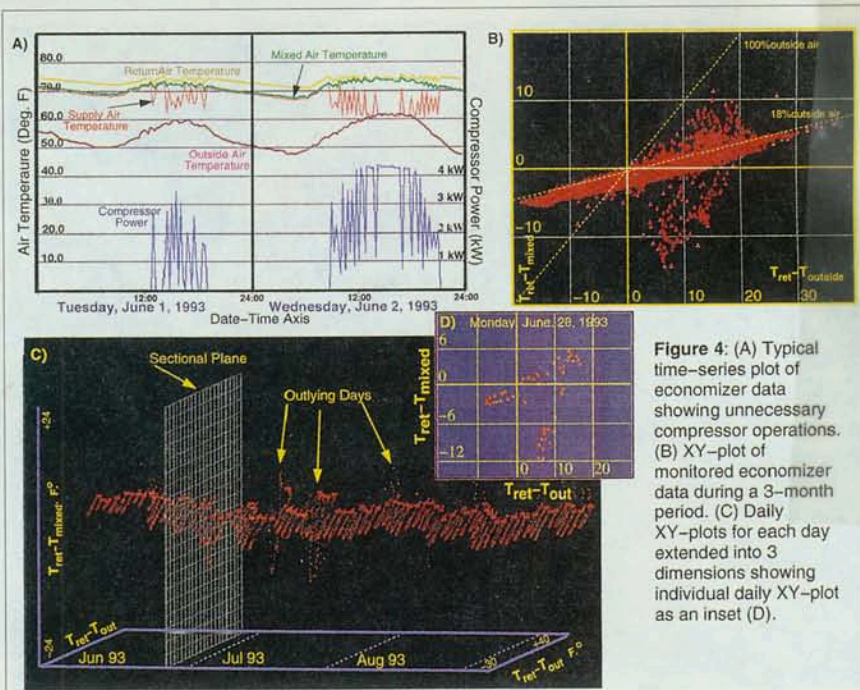


Figure 4: (A) Typical time-series plot of economizer data showing unnecessary compressor operations. (B) XY-plot of monitored economizer data during a 3-month period. (C) Daily XY-plots for each day extended into 3 dimensions showing individual daily XY-plot as an inset (D).

tween September 27 and November 11, 1993, during the late evening. The lights are on more than one would expect at this time of night if the occupancy sensors were functioning as intended, switching off lights in the absence of activity in the area. When building managers saw this first anomaly, they investigated and discovered that a security guard making his rounds until midnight each evening was tripping the occupancy sensors, reducing the expected energy savings. On November 11, new switches were installed which automatically turn off the lights but require manual turn on. Energy use went from 68 to 62 kWh (245 to 223 MJ) per day, yielding an additional 9% energy savings.

The data show another problem relating to the dimmable ballasts that were installed as a retrofit energy conservation measure. On January 10, an electrician accidentally reset the ballasts to their maximum settings (from 6 to 7.5 kW). During the following two months—a period in which lighting data visualization was not carried out—the lighting energy use increase of 18% to 73 kWh (263 MJ) per day went unnoticed. The increase is visible on the diagram as the block of red horizontal stripes in Figure 2. When data for this period were retrospectively analyzed, the problem was identified, and on March 15, the dimmers were reset correctly. Data visualization played a critical role in detecting the problem. The human eye would not detect the small changes in illumination that have such a large effect on power consumption.

Another problem visible in the post-January-10 interval is a second rise in consumption during the night hours. This appears to have been caused by the installation of incandescent lamps in a number of previously unlamped sockets in the building's lobby where no occupancy sensors were present. Another feature here is the slight offset in the first five bands of morning data (upper left) between the < 1 kW and 1 to 5 kW zones. This offset was caused by the switch from daylight saving time to standard time in early November.

• **Faulty Outside Air Temperature Sensor:** Faulty sensors are common in buildings and have significant implications for

energy efficiency. Consider the data collected from an outside air temperature sensor during the entire year of 1992 in San Ramon, California. Most EMCs use such a sensor to control the chiller lock-out or determine the effectiveness of economizers and evaporative coolers. At a first glance, a common time-series plot of the outside air temperature (Figure 3a) suggests reasonable behavior of the variable. However, a careful observer would notice the curious plateaus indicated on the Figure. Visualizing the frequency at which a given temperature interval occurred as a histogram (Figure 3b) reveals an unsuspected problem with the sensor. A smooth Gaussian-type distribution around the city's mean temperature would be characteristic. The data displayed on the histogram suggest the implausible circumstance that a temperature of 64°F (17.7°C) occurred more than twice as often as a temperature of 63°F (17.2°C) and 65°F (18.3°C). This sensor failed by "sticking" every 9°F (5°C).

We have seen other problems with data from outside air temperature sensors. Sensors misplaced in the hot air stream of the condenser exhaust record erroneous values above the actual outside temperatures. In such a case, the problem would be visualized by plotting daily profiles of outside air temperature with another point corresponding to the condenser's status. If a sensor is located too close to the roof of a building or not properly shielded, false high temperature readings may allow the EMCS to turn on energy-intensive mechanical cooling before it is really necessary. Visualizing daily, un-averaged temperature profiles such as the time-series in Figure 3a can help detect this error.

• **A Malfunctioning Economizer:** Economizers in HVAC systems bring in outside air to cool a building when the air meets the appropriate psychrometric conditions, saving energy used by the compressors that cool the building mechanically. However, economizers are plagued by failed dampers or improper control settings and do not always perform optimally. The economizer in this case study is part of a 7.5 ton (26 kW) package HVAC unit on a 7,300 ft² (730 m²) office building in Auburn, California, which has a dry summer climate. Although these data were analyzed retroactively and no channels could be established for operator feedback, this case study presents three data displays that could provide building operators with progressively richer information to identify and diagnose economizer problems.

Figure 4a shows a common profile of the mixed air, supply air, and outside air temperatures, as well as the compressor's power during a two-day period from June 1-2, 1993. Viewing the compressor power (or even compressor status) with this profile suggests that the economizer is not

functioning correctly because the compressor is running even when the outside air is cooler than the supply air and latent cooling loads are not significant.

Although scrolling through daily profiles provides detailed information about the economizer, it does not provide a picture of the economizer's overall performance. An XY-plot of the difference between the return air temperature and the outside air temperature ($T_{ret}-T_{outside}$) versus the difference between the return air temperature and the mixed air temperature ($T_{ret}-T_{mixed}$) summarizes three months of data relating to the economizer (Figure 4b). This Figure displays data collected between May 29 through September 9, 1993 at 15-minute intervals. The dotted line represents an outside

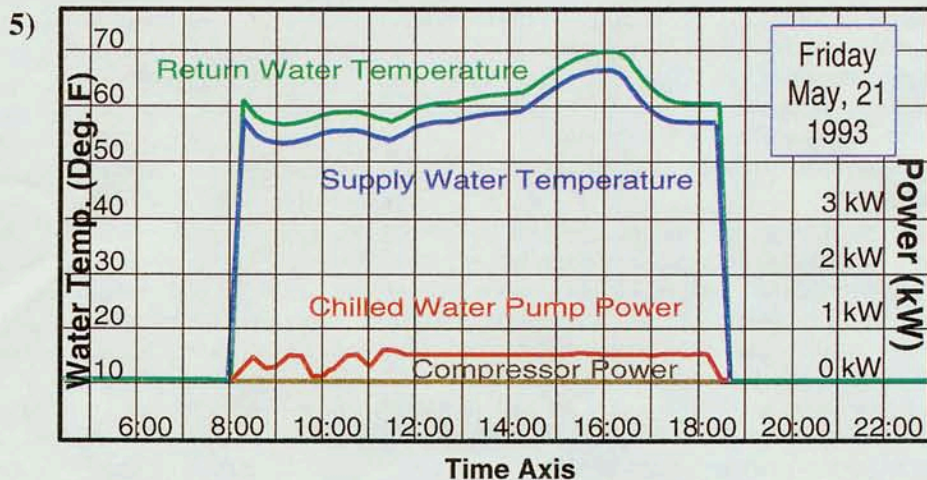


Figure 5: Daily profile of split-system chiller shows pumps are operating without the compressors.

air fraction (OAF) of 1 where 100% outside air supplies the building. The data in this display suggest three possible operating regions:

1. **Damper Stuck:** Most of the data are clustered around an OAF of 18% which suggests the damper's position does not vary.
2. **Correct Operation:** Some points are scattered between OAF=100% and OAF=0% suggesting the economizer is in fact varying and operating correctly.
3. **Mysterious Operation:** Points in the lower right quadrant suggest the anomaly that $T_{mixed} > T_{ret} > T_{outside}$. This would be impossible without the addition of some heat.

Although the density of data in Figure 4b suggests that the economizer is often stuck at an OAF of 18%, some information is lost when data from all of the days are displayed on one 2-dimensional graph because times and dates cannot be correlated with particular data points. The conditions and chronology corresponding to each of the three regions cannot be known. Since regions of the data display become saturated with data points, the relative time spent operating in each of the three regions cannot be clearly determined. Extending this display into three dimensions by creating an XY-plot for each day (Figure 4c) shows that there are only about five days that deviate from region 1 described above.

While visualizing a 3D display as in Figure 4c, a sectional plane can be passed or even animated through any day. Data from this single day can be displayed simultaneously as an in-

set XY plot (Figure 4d). Animating this 2D XY-plot through time adds an additional dimension to the data and can indicate trends correlated with the time of day or the hours when the building is not occupied. When the sectional plan was passed through the entire 3D display, the XY inset clearly showed collinear data points falling around 18% OAF for all except five days. These five days primarily had mysterious patterns when data points fell in the lower right quadrant (described above as region 3) as shown in Figure 4d. The user can view the dates and times of these anomalies and then display the anomaly differently, for example, in a detailed time-series plot. The analyst can display other relevant parameters such as compressor power, fan power, or relative humidity and see the exact conditions under which the anomaly occurred. In this case, this analysis showed all of the "mysterious" days corresponded to times when the supply fan was not operating and heat from either the burner, sunlight, or compressor heated the mixed air. This discovery indicated that the economizer was in fact never operating correctly. Visualizing the correct variables with the correct displays quickly allowed analysts to answer a variety of diagnostic questions as they surfaced.

Quantifying the energy savings from malfunctioning economizers is difficult because the economizer contributes to a varying fraction of the cooling load. In some climates, latent loads must be considered as well. Comparing the monitored and intended performance of an economizer provides the best quantification. To estimate the energy lost due to the malfunctioning economizer in this case, we took the difference between calculated the total measured energy used by the compressor and measured energy used by the compressor only when the outside temperature was lower than the supply air temperature. During the six-month period from June through December, 1993, 11% of the compressor's total energy was used unnecessarily to cool the building.

Although 11% of the compressor's total energy could have been saved by correctly adjusting the economizer, this only accounts for 244 kWh (878 MJ). However, running the compressors prematurely ages a valuable piece of capital equipment. To estimate these effects, we compared the total hours that the compressors were running and the hours that the compressors were running when the outside temperature was lower than the supply air temperature. During the six-month period, 28% of the multi-stage compressor's total runtime was unnecessary from an environmental control standpoint. However, from a maintenance standpoint, periodic operation may be beneficial. Although not the case in this particular example, this type of analysis can also identify problems that could compromise indoor air quality.

• **"Relational Checks" in an HVAC System:** The mechanical systems in large modern buildings can contain hundreds of components. Not surprisingly, these complicated systems do not always perform optimally. Visualizing data collected from the HVAC components helps building operators in an area of diagnostics commonly referred to as *relational checks*. We define relational checks as comparing two or more systems to ensure that both are operating as designed. For example, an air handler should not be simultaneously heating and cooling the supply air (assuming latent conditioning is not required). Although these relational checks may appear obvious, they are common malfunctions in buildings because the building sys-

tems can often meet the required load (albeit inefficiently) in spite of them.

A first step in performing relational checks is reviewing the mechanical drawings or control diagrams of the building to determine how the systems were intended to work. For example, in a simple water-air cooling system, the design intent would be that the chilled-water pump not be running if the compressors are not running. Actually, in some systems, the pump should be running slightly more than the compressors. After the compressors shut-down, the water and the refrigerant are still cool enough to absorb some heating load. Circulating the water through the chiller and air-handler coils takes advantage of this residing "coolth." However, the daily profile in Figure 5 shows that on May 21, 1993, the compressor never turned on, but the pump was running almost all day at its maximum 0.6 kW. Scrolling through months of data, we noticed several other days similar to this one. In addition to wasting the energy to run this pump, unnecessary operation prematurely wears the pump. The building's mechanical contractors were notified and corrected the error in the EMCS program that caused this malfunction.

Collecting the data necessary to perform relational checks is relatively easy. Most EMCSs monitor each component's "status" and can therefore indicate when it is running or the total hours of operation. However, such status indicators cannot quantify parameters such as speed, current, or energy consumption. Some relational checks can be performed with run-time data alone. For example, in the system described above, the pump and the compressors should be running almost the same amount of time. If one runs significantly more often than the other, there is likely to be a problem. Monitoring run-time is generally one of the least expensive measurements because only a single scalar value (time of operation) is recorded as opposed to an array of values necessary to express a time series. We have even seen pocket temperature sensors taped to a motor to determine when it was running by the increase in temperature!

Returning to Figure 5, we cannot ignore the 3.5 °F (1.9°C) error in the calibration of the supply and return water temperatures. Looking again at the design documents, it is clear that if the compressors are not running the refrigerant loop is not moving and these sensors should read the same temperature. ASHRAE recommends that delta-temperature measurements in a water loop be accurate within 0.5°F (3°C) (ASHRAE Standard 114-1986). These results were presented to the building's mechanical contractor who recalibrated the sensors. The energy effects from this miscalibration are subtle. If the sensors were connected to an EMCS, then the particular HVAC components controlled by the chilled water temperature could have been triggered before they were necessary. Modeling the actual and designed performance in a building simulation package would be the most reliable method of determining these energy effects. However, the sensors in this case study were installed to evaluate the energy consumption of this chiller, which was installed as a retrofit energy conservation measure. If we assume a full-load operating delta-temperature of 10°F (5.6°C) in the water loop, the error in calculating the COP of this chiller will be at least 35% (this is only the error caused by the temperature sensors and does not even consider that when calculating the COP of an air-water cooling system, it is also necessary to measure the water flow, which generally has an error of 5-10%) and therefore unreliable.

Visualizing monitored data from these systems helped to identify this measurement problem.

Most EMCSs have alarms that can automatically alert the building operators in the event of relational malfunctions. However, in some cases it is difficult to program these alarms so that they do not trigger falsely. When inundated with false alarms from the control systems, an operator's first reaction is to disable them. Although the relational alarms are often helpful, a knowledgeable operator will diagnose more problems using an efficient interface to scroll through data manually. For example, this case study began by discussing relational checks and progressed to discussing sensor calibrations. As indicated by this progression, it is common to find problems other than those originally sought when diagnosing HVAC systems. Until more applications of fuzzy logic appear in the building controls industry, manually visualizing monitored data using efficient interfaces and data displays will be an effective method for HVAC diagnostics.

Implementing Data Visualization

The case studies presented above demonstrate the use of data visualization as a tool to facilitate the detection and quantification of performance problems. Incorporating data visualization with operation and maintenance requires that several issues be addressed.

When does visualization take place? Data visualization could be carried out in support of the commissioning effort, at regular intervals during a facility's life, or on a continuous basis.

What is visualized? During commissioning, visualization of most, if not all, points collected might be appropriate. During routine operation, only selected points

might be monitored (for example, those that related to components that frequently malfunction or to systems that are responsible for a large percentage of the facility's energy consumption).

Who does the visualization? The commissioning agent, the building operator, and specialized consultants might each carry out visualization at some stage of a facility's life.

How is the visualization accomplished? Commissioning agents, operators of large facilities, and consultants might carry out visualization often enough and on a varied enough set of points to warrant the use of high-end tools (workstations running sophisticated data visualization software), while operators of small or moderate facilities might be better served by customized spreadsheet packages that allow easy tracking of key end-use systems. Operators and analysts would be well served by a handbook that provided problem descriptions, a summary of data points that should be monitored to identify these problems, and a description of convenient means to visualize the data.

In all cases, the visualization must be part of the performance monitoring process, with a clearly defined means of feeding back the results to those in position to correct observed problems. If a specialized consultant implements visualization in a building, they benefit from a facile use of a high-end data visualization and a fresh approach to the building. However, they may suffer from costly time spent learning the buildings systems. On the other hand, the inverse will be true if visualization takes place by the system's

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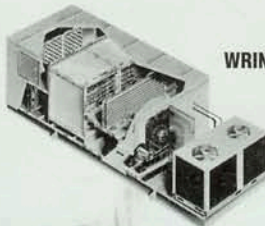
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designer or commissioner. In all cases, data visualization is a diagnostic tool which requires a skilled user who understands both the tool and the systems it is analyzing. The appropriate process is highly case-dependent and driven by a facility's objectives and resources.

Conclusion

The discussion and case studies presented in this article indicate that data visualization can help achieve substantial improvements in energy management, equipment maintenance, and occupant comfort in commercial buildings. Data visualization alone cannot improve a building's performance and must be integrated to an O&M plan to be effective.

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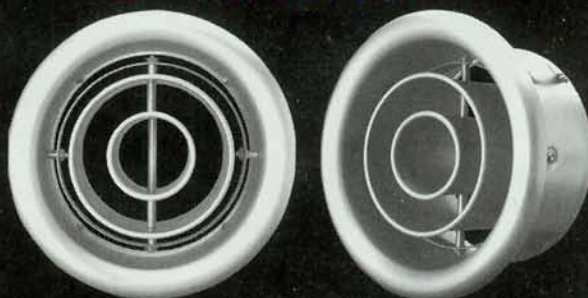
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